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ASSESSMENT OF TREE OF HEAVEN (*AILANTHUS ALTISSIMA*) SPREAD DYNAMICS ON EXAMPLE OF SZEGED (HUNGARY)

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Summary: The spread of invasive species means a serious ecological problem worldwide. The modified environmental conditions in the cities significantly influence (mostly impair) the urban vegetation. In these circumstances, invasive species with a wide ecological tolerance enjoy a significant advantage. In our study, the possible spreading factors of the Tree of heaven (*Ailanthus altissima*) were examined on the example of Szeged (Hungary). The survey was based on the Local Climate Zone (LCZ) system. Several important characteristics of urban space parameters were processed, such as potential direct irradiation, the land cover and the urban heat island. We found not too strong correlation for example between the land cover type or the heat island intensity in June and the number of trees.

Key words: urban invasive species, Tree of Heaven (*Ailanthus altissima*), spatial analysis, urban built-up investigation

1. INTRODUCTION

The global anthropogenic transformation has significant local implications as well. This includes a particularly dangerous environmental phenomenon, the spread of invasive species worldwide (Walter and Gillet 1998). The diminishing role of geographical distance will further facilitate the expansion of these species.

The complex surface structure of cities, the different heat capacity and run-off properties of the artificial materials used in the built environment have caused the change of climatic conditions in urban areas (Unger et al. 2014). This usually leads to heat excess in the cities. These environmental conditions have significantly influenced the composition of the urban vegetation. The cumulative anthropogenic effects create unnatural habitat conditions for species that can tolerate relatively little. Thus, invasive species with a wide ecological tolerance enjoy a significant advantage (Bartha 2002, Gulyás and Kiss 2007). Heat and drought tolerant tree species, such as the tree of heaven (*Ailanthus altissima*) may have a serious advantage over native species. Temperature trends due to climate change are likely to favour species with an aggressive growth strategy, which the urban impacts of climate change can strengthen even further. The urban problem of invasive species is a very complex topic since the negative effects of urbanization and climate change are summed up.

Ailanthus is one of the most dangerous invasive species in the Central European flora area (Landenberger et al. 2009). It has all the features that enable a plant to withstand the changed circumstances in both natural and anthropogenic environment (Udvardy and Zagyvai 2012). The aggressive growth strategies of the species make it capable of significant propagation, thus it plays a role in not only degrading urban vegetation, but it also contributes to significantly reducing biodiversity outside the city in near natural vegetation (Lawrence et al 1991, Kowarik and Sämuel 2007, Csiszár et al. 2012). Due to a strong root sprouting ability, it can cause severe damage in the urban environment, i.e. to roads, sidewalks, walls, damaging the building structure as well (Udvardy 2004). Despite the seriousness of this problem, very little research has so far been conducted on the subject. However, the many ecosystem disservices caused by this species require examination. In our research, we examine what methods can be used to address this complex urban environmental issue. In order to prevent the spread of the species it is necessary that we know the factors most influencing propagation.

2. THE STUDY AREA AND METHODS

2.1. Description of study area

Our study area is located in southern Hungary, Szeged. In Trewartha's system the country is classified as category D1 (continental climate with longer warm seasons), and within this the Great Plain is characterized by warm, dry climate. Thus, the climate in the immediate environment of Szeged is also characterized by high summer heat, when drought can also develop, high levels of sunshine duration, low humidity and cloud cover (Péczely 1979). Szeged is the largest city in the Southern Great Plains, both spatially (281 km^2) and in terms of population size (~ 162,000 capita) (KSH 2015). It is a strongly urbanized area, a significant part built-up. The sample areas were chosen in the area of the city called 'Ó-Szeged', northwest of the river Tisza, because this area well reflects the classic city structure and built-up types of Szeged. As the assessment of the whole area of the city was not an option, we settled for a representative, area-proportional sampling method, which represents the variety of urban structures well.

On the basis of literature data we assumed that the urban spread of the thermophilic *Ailanthus* is influenced by the local climate-modifying effect of the urban environment in addition to the background climatic conditions (Kowarik and Säumel 2007, Kowarik 2008). Therefore, in the course of the designation of sample areas we took into account the already developed Local Climate Zone (LCZ) system in Szeged. The LCZ system is a relatively new method aiming to refine the study of urban climate, which takes into account the urban surface reactions and thermal parameters in a complex manner (Unger et al. 2014). The elements of the LCZ are a few hundred meters to several kilometres areas that are characterized with more or less uniform land cover, structure, material types and anthropogenic energy emissions. The method has the advantage that the number of subtypes is relatively low and they are objectively separable from each other. Each LCZ type has a characteristic temperature distribution, which manifests itself most prominently over relatively flat and dry surface, calm and clear nights (Stewart and Oke 2012). Because of the built-up conditions of Szeged, only 6 LCZ types were isolated in the city (LCZs 2, 3, 5, 6, 8, 9), of the internationally agreed LCZ types (Unger et al. 2014) (Fig. 1).

The applied survey method somewhat combines a sampling method used in open areas with those matching urban structures well. Accordingly, the sampling areas are located inside of the third (and outmost) boulevard. Within the LCZ types 200-m radius circle sampling plots were designated based on random sampling (30 plots in all). The number and overall area of the plots in each LCZ reflects the areal proportion of that particular LCZ type. In the sample plots we examined *Ailanthus* individuals located in public areas, because access was not possible on private property. Field surveys were carried out between June and September in the summer of 2014. All accessible trees were recorded according to a standard wood cadastral if their diameter at breast height (DBH) exceeded 5 cm. The height, trunk height, DBH, crown diameter, and different parameters of the health condition of the trees were recorded. These data were analysed using SPSS 22 statistical software.

Fig. 1 LCZ types of Szeged and sample plots of the investigation

2.2. Potential direct irradiation investigation

The maximum potential amount of light available for photosynthesis was estimated using a potential direct insolation map. We defined potential direct insolation as the amount of direct irradiation, which may come from the sun at the specific geographical location, at a given time of day and season of the year, regardless of the state of the atmosphere. In order to prepare this we used a digital terrain model of Szeged, including the buildings. The aim of the process is to show how much shadows the buildings cast over the surrounding areas, and how they limit the incoming direct radiation. The analysis was carried out for the average growing season of the *Ailanthus* (between April 1 and October 31), with a time step of 7 days and 5 hours within the day. For this analysis, we used the SAGA GIS software. As a result we got the values for each cell of the DTM and calculated the average, minimum and maximum value for each plot. The resulting potential direct insolation values and the appearance of *Ailanthus* within the sample areas were compared in order to look for a connection between the two phenomena. The direct irradiation data relating to individual trees, and averages of the LCZs and the sample areas were calculated using QGIS software.

2.3. The effect of built-up area

In order to prepare a simple surface cover map (concentrating on built-up/green space) we used the Department of Climatology and Landscape Ecology's building database of Szeged, a 0.5 m resolution orthophoto created from 4-band (IRGB) UltraCamD aerial images as well as a surface model generated from that (Gál and Unger 2012).

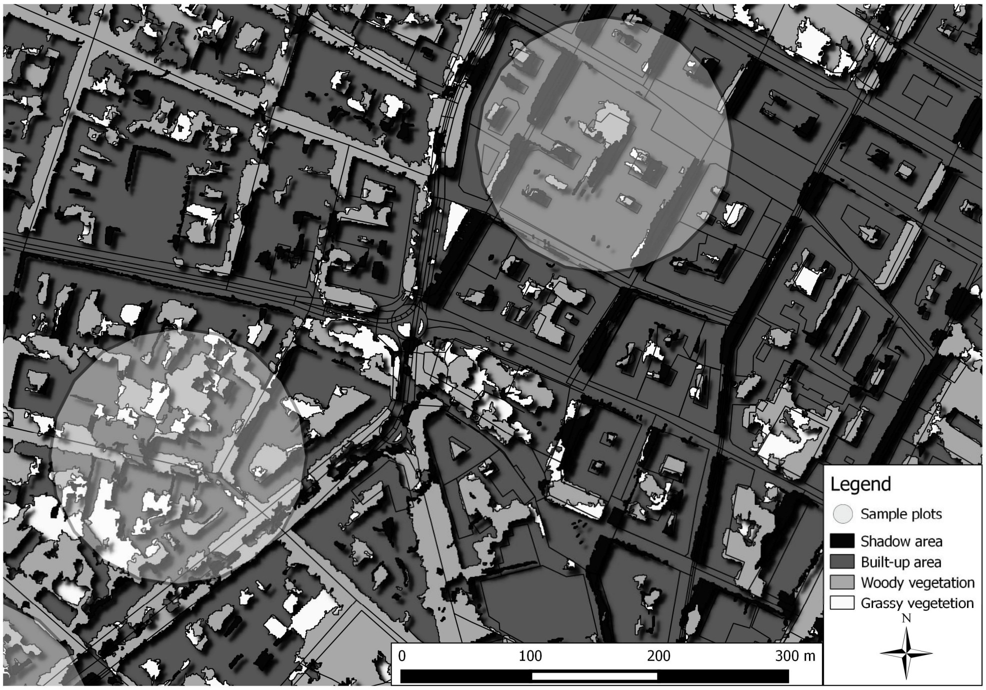

Fig. 2 Surface cover categories according to eCognition classification

The classification was carried out with eCognition 8.7 software, with a simple set of rules using thresholds. Four categories have been identified: grassy vegetation, woody vegetation, built-up area and shadowed areas (Fig. 2). The green areas were determined using the vegetation index NDVI. Due to the light conditions at the time of taking the photos, there were strong shadows of the buildings and trees on their northwest side. In these locations determining the actual land cover was really precarious and difficult, so overshadowed areas are considered lack of data from the point of view of the analysis. The situation is somewhat similar with ground under trees, some of these areas may be suitable for *Ailanthus* colonization, however but the chances to determine such places from above are limited.

2.4. Heat island investigation

The urban heat island (UHI) is one of the most important effects of climate change in urban areas; it is excess heat appearing at certain times. The heat island is best characterized by its intensity, which is very closely related with the landcover and built-up area (Balázs et al. 2009, Lelovics et al. 2013). The temperature differences show inherent high spatial heterogeneity within the city as well. We tried to find a relationship between heat island intensity and the presence and health conditions of *Ailanthus*. The temperature data for heat island intensity were obtained from the Urban-Path project's climate stations (Unger et al. 2014) (22 monitoring stations with average and maximum heat island intensity data, with a monthly temporary resolution from March to August 2015). We carried out an IDW (Inverse Distance Weighted) interpolation on these point data using QGIS software, in order to prepare simple maps of the monthly average and maximum heat island intensity in Szeged.

3. RESULTS AND DISCUSSION

During the field survey 184 adult specimens of *Ailanthus* were measured. In the downtown areas (LCZs 2, 3) the occurrence of *Ailanthus* is characterized by a uniform distribution and a low number of specimens (Table 1). A possible reason for that is the high proportion of built-up areas, which does not provide favourable living conditions for any plant.

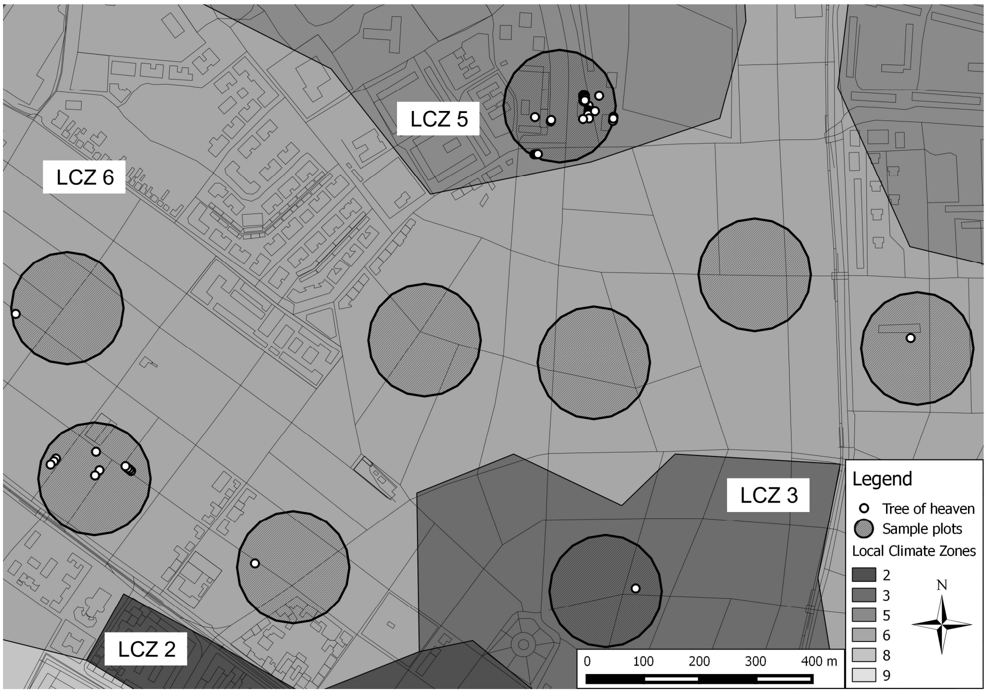

Fig. 3 Distribution of tree of heaven in some sample plots

However, the spatial distribution of the trees could be influenced by the fact that public green surfaces are better kept in the downtown areas, so there is a higher chance that unwanted *Ailanthus* specimens would be removed than in suburban areas. The highest population density (tree per hectare) was observed at LCZ 5 (open construction, medium-height buildings), and it was also in this type that the most individuals (in absolute term) were recorded. Within the LCZ, the distribution is uneven; it is the most dense in the eastern and northern part of the city. In our experience, most of the trees occur in disturbed housing estate areas.

Table 1 Distribution of *Ailanthus* by LCZ areas and population density per hectare (total area= 10,509.94 ha, 1 sample spot=3.09 ha)

LCZ	Area %	Tree count	Sample plots area (ha)	Tree count/ha
2	5.99	1	6.18	0.16
3	6.34	4	6.18	0.65
5	23.71	128	18.54	6.90
6	56.15	44	52.53	0.84
8	6.10	7	6.18	1.13
9	1.71	0	3.09	0

LCZ 6 and 8 are not characterized by a large number of specimens. In the open and less built-up areas (e.g LCZ 5) more specimens are found, than in the city centre, probably because there is more space for growth (Fig. 3).

During the field survey we noted (and on the survey map it is also outlined) that along the boulevards the amount trees is higher. Therefore, the busy boulevards, meaning a major disturbance seem to increase the number of *Ailanthus* trees.

3.1. Health conditions

According to the standard wood cadastral mapping method, on which our survey was based, the state of the tree can be defined on the basis of the health conditions of the tree trunk and the canopy. During the survey we recorded the trunk injuries (eg. bark injuries, rot, cavity) and the canopy damage (eg. broken branches, decay of the top, crown base injuries, cavity) and tree health conditions were characterized as the sum of these. A deteriorating health status can inform about environmental conditions that do not correspond to the trees' needs.

Despite *Ailanthus* being described in the literature as an urbanophile species, in the city its health conditions were far from perfect. Looking at all the trees, the condition larger or smaller care gaps predominated. Well-tended for specimens were not found, and only approx. 8% of the total population (184) could be classified as one of the two better conditions (tended and care gaps category). The majority (74.73%) fell into the category serious care deficiencies (serious care gap category). Trees in the worst condition (the untended for category) represent 17.03% of the total (Fig. 4).

The health conditions of trees vary according to LCZ as well. Because each LCZ zone has similar land cover structure and urban climate features, the differences in the health conditions of the trees between the different zones may be informative. Tended trees (i.e. individuals developing healthily in most respects) are only found in LCZs 5 and 6. In these zones, the picture is the most heterogeneous, because the number of samples is the largest. In the other LCZs the low number of individuals distorts the evaluation, although it is striking that in LCZ 8 a significant part of the trees is in the untended for category.

The more neglected and deteriorated the studied areas are the worse the health conditions of the trees. In the housing estate areas (LCZ 5) green space is usually less tended than in the city centre, so the trees are not in such good condition either. The detached houses area (LCZ 6) is similar with the difference that here the number of tended trees is slightly greater. The trees of LCZ 8 are in the worst condition, but these are industrial sites, where green surface management is not a priority.

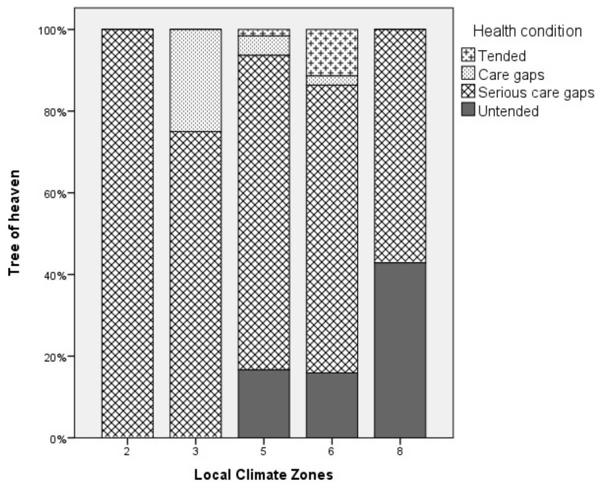

Fig. 4 The health conditions of trees by LCZs

Ailanthus often responds to urban conditions by drying. We observed that the main and smaller branches started drying in the case of several individuals of different sizes, but often even the tree top dieback is apparent. Further typical injuries include trunk rot and longitudinal cracks, which subsequently further aggravate the health conditions of the trees. Root growth is confined by the narrow space so the *Ailanthus* often develops its roots pushing the surrounding pavement, however in turn it does not grow at a healthy pace. Cavities are not typical for *Ailanthus*.

3.2. Potential direct irradiation investigation

We investigated the influence of irradiation on the number of trees at several scales. At the tree-level, the individual tree characteristics (size and health conditions) were compared with the potential direct irradiation for the whole study area. Then the relationship between the number of trees and the plot-level irradiation characteristics was examined for both the whole area and the LCZs separately.

Concerning the dimensional characteristics of the *Ailanthus* in the study area small specimens are the most typical, a DBH of 15–25 cm and a height of 7–8 m are the most common; larger individuals are rarely found in the surveyed area. Based on statistical analysis neither DBH, height, nor the proportion of dead tissue shows appreciable correlation with direct irradiation. There are also no significant differences in the amounts of maximum potential insolation and the tree's site according to tree condition. This was the expected result, since the trees dimensional properties depend mainly on age and the habitat, which can be considered practically homogeneous within the city.

Next, we examined the plot-level relationship between the number of trees within the plot, and potential direct irradiation using Spearman's rank correlation. For the entire area (30 sample plots), the number of trees only showed a significant (negative) correlation with the maximum of the radiation ($r = -0.469$). This can be explained with the fact that the highest potential irradiation values appeared on building tops (due to the simplified building database, in which all roofs are flat) and in larger squares (of which there are few in the city).

Therefore, the highest maximum potential irradiation values occurred where there are large and tall buildings, mainly in the well built-up city centre, where there are few *Ailanthus* trees.

When considering the LCZs separately, there are only two zones (5 and 6), where the number of plots was sufficient in order to calculate correlation. LCZ 5 contains less plots but more trees whereas in LCZ 6 there are more plots with much less individual trees. In LCZ 5, the number of trees showed a strong positive correlation (r = 0.829) with the potential direct irradiation averaged for the plot. These results are more easily interpretable and they correspond to our experience in the field as well. In LCZ 5 we find more *Ailanthus* where there is more available amount of light. This LCZ is dominated by housing estates, i.e. high buildings and large, open areas with high amounts of light, where the *Ailanthus* has optimal growth area.

3.3. The effect of built-up area

One important difference between urban and natural habitats is that the former has varying degrees of built-up area, which greatly limits the spread of a species. Such abiotic limiting factors are rare in natural habitats. The land cover map of the area used four categories (grassy vegetation, woody vegetation, built-up, and shadow area). The category grassy vegetation is low green surfaces, typically grasses or small bushes. The woody areas include all mature trees. The built-up category contains all the artificial surface elements: sidewalks, roads, buildings and bridges. The creation of the shadow category was necessary in order to indicate lack of data – the shading effect of the buildings and large trees could not be eliminated. The analysis was carried out in 29 plots within LCZs 2, 3, 5, 6 and 8 (Fig. 5).

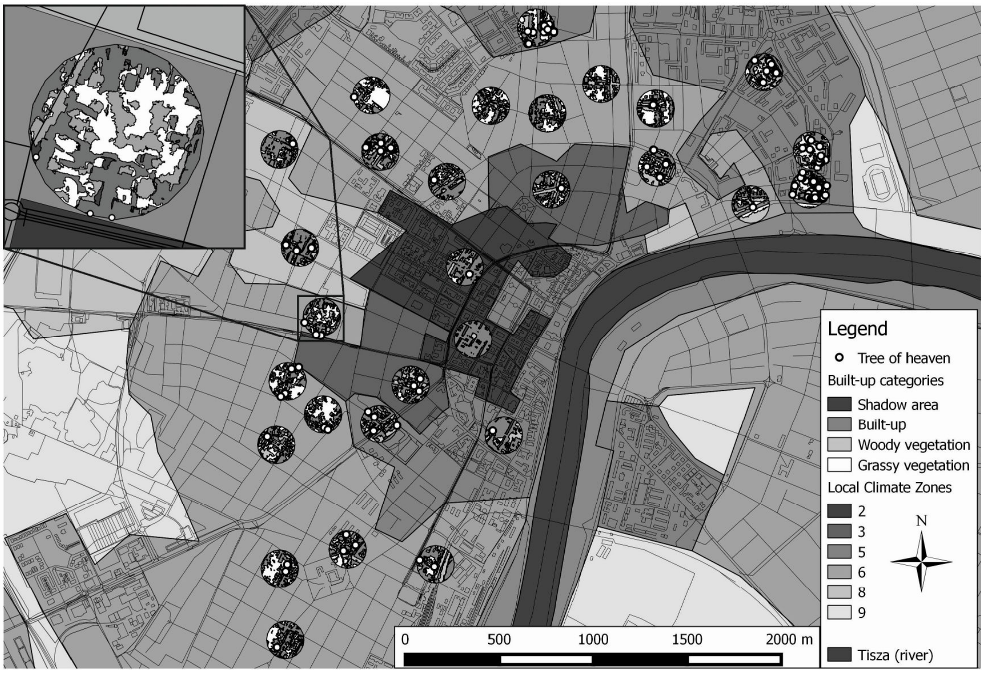

Fig. 5 The surface cover categories in sample plots and the LCZ background

The built-up rates are different within the various LCZs (Fig. 6), LCZs 2 and 8 have the highest proportion of built-up areas. At the same time, in LCZ 2 the ratio of the shadows is very high, due to the presence and shading effect of high buildings. In the other LCZs, the built-up ratio is lower by almost 30%. In LCZs 5 and 6, the built-up areas show similar proportions, however the LCZ 5 has slightly higher proportion of woody vegetation.

In the correlation analysis (including all 29 plots) the relationship between the total area of the categories (per plot) and the number of *Ailanthus* trees in the plot was examined.

Weak to moderate correlation was detected between the number of trees and the ratio of woody vegetation-covered areas. This is partly (but not entirely) due to the fact that the *Ailanthus* trees themselves have fallen into the woody vegetation category. In addition, it is also implied that small trees may often spring up at the foot of larger trees. Examining the LCZs individually, it is only in LCZ 5 that a strong positive correlation could be detected between the number of trees and the grass vegetation area. In this LCZ housing estates are frequent with major open grassy areas between the buildings. In order to refine this analysis, further surveys will be needed, including increasing the number of sample plots.

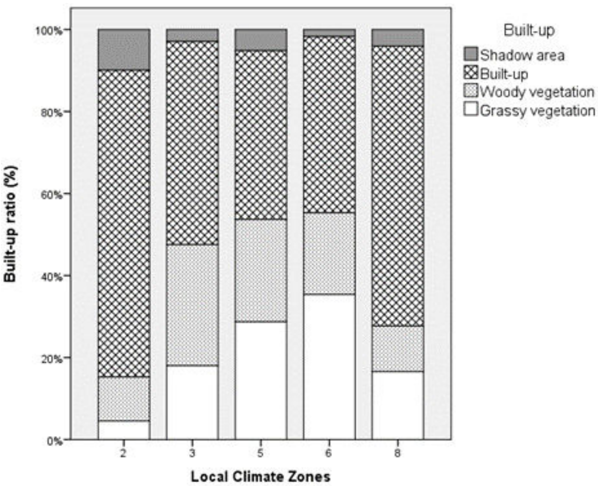

Fig. 6 The built-up categories by LCZs

3.4. Heat island investigation

The temperature differences show a high spatial heterogeneity within the city, and this is why we chose to compare the heat island intensity with the occurrence and health status of *Ailanthus* trees. Heat island intensity varies according to season but the values are generally higher in the downtown areas. In many cases, however, such as the maximum value of the May heat island intensity can be high in the outer zones LCZ 5 as well. The number of *Ailanthus* trees in the plot and the heat island intensity generally showed no significant correlation, except for the June average heat island intensity with which it showed a weak negative relationship.

The sample plots characterized by greater number of *Ailanthus* trees are mostly located in low heat island intensity areas (Fig. 7) (the relationship is significant at the 10% level, the specific value was 5.2%). This result is presumably linked with the ratio of built-up areas, as heat island intensity is usually greater in the more densely built-up areas. In such areas growth possibilities for trees are also limited by the lack of available space.

We carried out further analysis concerning the relationship between heat island intensity and tree health conditions. We plotted the average values of heat island intensity in the vicinity of the trees according to the health conditions categories (Fig. 8). The results were verified using the Mann-Whitney U test.

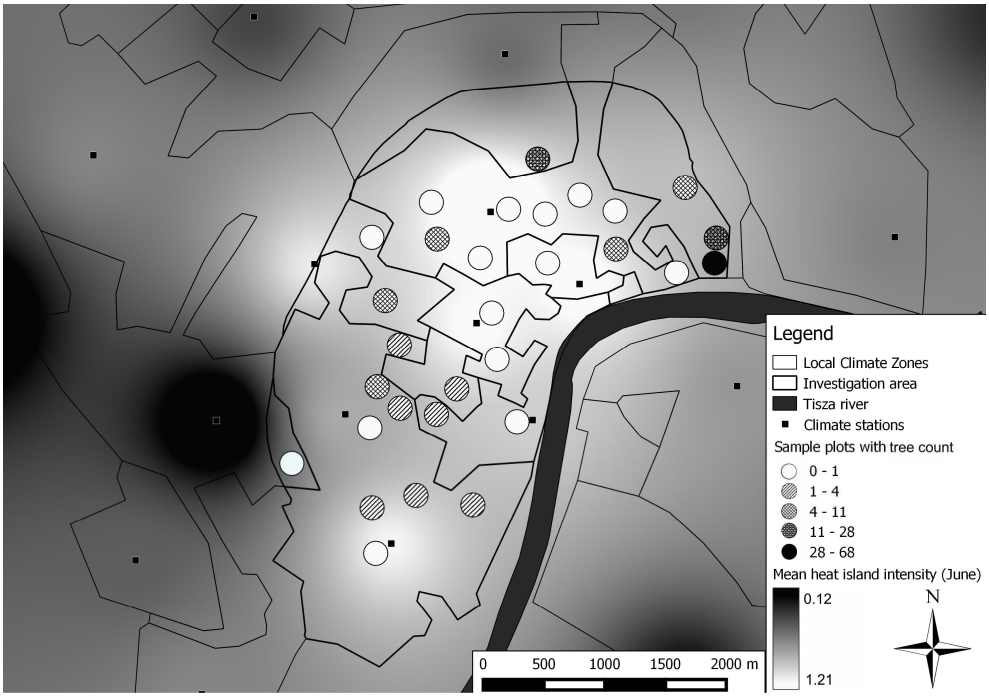

Fig. 7 The average heat island intensity (°C) in June 2014 with the tree numbers in the sample plots

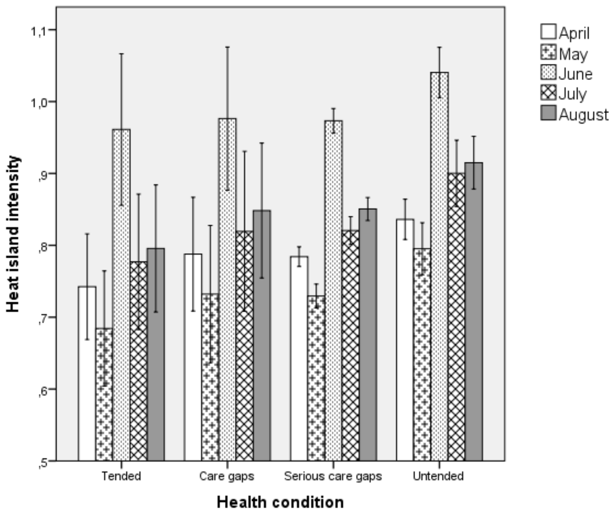

Fig. 8 The heat island intensity (°C) and the health conditions of trees (Error bars represent the 95% confidence interval)

Based on the results, the trees in worse conditions have higher heat island intensity values associated. The highest means were found where trees were in the worst condition (untended). It is clear that for trees in a bit better condition (serious care gaps category) this value is lower. Although the other two categories seem to follow a similar trend, there are too few trees and consequently too high standard deviation. We can conclude that trees considered to be in worse condition were typically found in areas characterized with higher heat island intensity. This analysis was run both with the monthly average and the monthly maximum heat island intensity values, and the results were the same.

Overall, the strongest relationship with both the number of trees per plot and the health conditions were found with the June heat island intensity data, when the UHI is strongest. The correlation with the number of trees is mostly not significant, but it is significant for the June data at the 10% significance level. The weak relationship probably originated from the fact that (1) heat island intensity can be one of several factors influencing the condition of the trees (2) the heterogenity of the actual UHI intensity is probably greater than that represented by our interpolated map. The trees occur less in areas with higher heat island intensity, as these are also the most densely built-up areas, least suitable for colonization for any type of vegetation. When investigating the relationship between tree condition and heat island intensity it can be seen that trees in worse conditions are usually found in areas with a higher heat island intensity (considering both the monthly average intensity and the maximum). The fact that there is a difference between individual months, however, suggests that there is a real link between the microclimate and the studied species.

4. CONCLUSIONS

The analysis of the urban appearance of invasive species is a complex and little-researched area. In our research, we tested a method often used in natural environments, in order to find out whether it is suitable to examine the spread of the *Ailanthus* in an urban environment. As a city has extremely complex ecological relationships, the results are not always clear. In this phase of the study it can be seen that in the densely built-up areas of the city centre, the chance of *Ailanthus* occurrence is small. This has several, interconnected reasons, from the quantity of available light to the extent of heat island intensity, which probably affect the trees in a complex manner. The trees have a very heterogeneous distribution and it is difficult to clearly explain the large differences in density.

The accuracy of the results could be achieved by further increasing the number of sample plots, as a large and representative volume of data provides more reliable and general results. Additional parameters e.g. precipitation at the plots or the amount of nutrients available could improve the complexity of the research.

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